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ON THE PENETRATING RADIATION AT THE SURFACE OF THE EARTH

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Communicated by Prof. McLENNAN

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On the Penetrating Radiation at the Surface of the Earth.

By G. A. CLINE, B.A.

(Communicated by Professor McLennan, and read before the Royal Society of Canada on May 26th, 1909.)

I.—INTRODUCTION.

During the last few years a number of investigators have made a study of the penetrating radiation which is known to be present at the surface of the earth with a view to locating its source or origin. The presence of radioactive substances in the soil and of radioactive emanations in the atmosphere suggest both the earth and the atmosphere as sources for part at least of this radiation. It is possible, too, for such a penetrating radiation as that present at the earth to have its origin in the sun or other celestial bodies.

It is known, besides, that the amount of radioactive emanation present in the atmosphere at any time is largely dependent upon the barometric changes which have taken place for a short time previously, and upon the precipitation which has occurred in the locality concerned. If then the penetrating radiation comes largely from the atmosphere it would follow from the above considerations that frequent though perhaps irregular changes should occur in the intensity of the radiation at any particular locality.

If the sun, however, contributed the major portion of the penetrating radiation we should then expect to find regular daily variations in its intensity. On the other hand, if the greater part of the penetrating radiation has its origin in radioactive substances in the soil and rocks, we should expect to find but little, if any, variation in its intensity throughout the day or even from day to day in any particular region.

One of the first to note a diurnal change in the ionisation of air contained in closed metallic cylinders was J. J. Borgmann.[1] His experiments were carried out in the neighbourhood of St. Petersburg. Among other results he found that the ionisation of the air in cylinders of copper, aluminium, brass, iron, zinc, tin, or lead, increased for some days after being enclosed, and finally reached a limit. This limit he found to vary from day to day and even during a single day. The minimum of ionisation noted by him was most frequently observed about three o'clock p.m.

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[1] Science Abstracts, 1905, No. 1580.

Mach and Rimmer[1] while investigating the emanation content of the atmosphere at Vienna also made so measurements on the ionisation of air confined in closed etallic vessels, and from their measurements they were led to conclude that the penetrating radiation was more intense in the mornings and in the evenings than at noonday.

Amongst others Wood and Campbell,[2] at Cambridge, England, made an extensive examination of the penetrating radiation for a daily variation. In their experiments they made measurements on the ionisation in different gases contained in closed metallic vessels of 6000 cc. capacity, and they used a sensitive quadrant electrometer as the measuring instrument.

From their experiments they showed that a periodic variation occurred in the ionisation of the enclosed gases having two maxima and two minima each twenty-four hours. They also shewed that the periodic variation was independent of the nature of the enclosed gas, and that the periodicity was independent of the metal of which the enclosing receiver was made. Their ionisation curves representing these periodic changes were found, too, to be approximately the same as the curves representing the variations of atmospheric potential. As to the magnitude of the changes noted, these experimenters found on the average that the variations in the ionisation which took place in any one day amounted to about 12% of the whole.

McKeon,[3] of Washington, U. S. A., made an attempt to study the radiation by examining the variations in the potential assumed by an insulated metal cylinder placed within and completely surrounded by a second metallic cylinder, 120 cms. long and 20 cms in diameter. In his observations he noted a double daily variation in the potential of the insulated cylinder. The effect measured in his experiments, however, does not appear to be exclusively dependent upon the intensity of the penetrating radiation.

Strong,[4] of Baltimore, also made a study of this penetrating radiation using a small enclosed gold-leaf electroscope as the measuring instrument. In his experiments he observed the loss of charge from this instrument in a variety of places including (1) a room in the Physical Laboratory at Johns Hopkins University, (2) a cistern filled with rain water, the electroscope being placed at the centre, and (3) a room in the open country in the State of Pennsylvania near Mechanicsburg.

[1] Phys. Zeit. 7, pp. 617, Sept. 15, 1906.
[2] Phil. Mag., Feb. 1907.
[3] Phys. Rev., 1907.
[4] Phys. Rev., July, 1908.

Strong from his measurements drew the conclusion that the atmosphere contributed by far the major portion of the penetrating radiation. He found the intensity of the radiation greater in summer than in winter, and he too noted a double diurnal period in the ionisation in his electroscope. Precipitation of rain or snow always produced a drop in the intensity of the radiation. But all changes in intensity were eliminated when he surrounded his electroscope with thick lead and iron screens. Strong's measurements are rather remarkable for the extremely wide variations which they indicated and it is difficult to account for them. On Jan. 30, 1907, for example, he observed ionisations at various times of the day represented by 12, 82, 100, 77 on an arbitrary scale, and again on Sept. 3, 1909, ionisations were observed represented by 25, 18, 50 and 155, 150, 42, 10, 15 on the same scale. Variations so extensive as these do not appear to have been observed by any other investigators and they seem to point to some very special and exceptional local conditions.

Some experiments were also made recently on this phenomenon by D. Pacini at Sestola, in Italy.[1] This investigator used an aluminium-leaf electroscope and studied the ionisation in air enclosed in large zinc receivers. He too found daily maxima and minima values in the ionisation. His minimum observations ranged from 8, 9, 10 to 12 ions per cc. per second while his maximum observations extended in some cases to as high as 30 ions per cc. per second. His ionisation values present a double daily period with two maxima at two to three o'clock and nine to ten o'clock, and two minima from seven to eight o'clock and from twelve to one o'clock.

Wulf,[2] too, who devised a new type of electrometer the movable system of which consists of a double conducting quartz thread, has applied this instrument also to the investigation of the penetrating radiation. His experiments were carried out at Valkenburg in Holland, both on the surface of the earth and in the chalk quarries in the neighbourhood of that municipality. He too found a parallelism between the intensity of the penetrating radiation and that of the atmospheric potential, maximum values being obtained for both phenomena in the summer about eight or nine in the morning and evening, and minima about noon and midnight. In winter the midday minimum was only slightly marked.

The amplitude of the morning variations was found to be about 16%, while that of the afternoon ones was about 10% of the total ionisation and the mean ionisation corresponded to from 25 to 30 ions per cc. per second. The ionisations observed in the measurements in

[1] Rend. Acc. Lincei, 18, 123-129, 1909.
[2] Phys. Zeit. 10, 1909, 152-157.

the chalk quarries were found to be only about 42% of those obtained on the surface of the ground.

In this connection it will be recalled that Elster and Geitel[1] observed a fall of 28% in the conductivity of air enclosed in an aluminium receiver when the apparatus was taken from the surface down to the bottom of a rock salt mine. It will be remembered, too, that C. S. Wright, in his experiments at Toronto, found the conductivity of air confined in closed metallic vessels in experiments on the ice of Lake Ontario to be about 46% less than in similar ones made on the lawn in the neighbourhood of the Physical Laboratory. It will be recalled too that the ionisation values obtained by Wright on the sand bars on the Island near Toronto, were but slightly higher than those obtained by him on the ice. The experiments at Toronto coupled with those at Valkenburg, and with those of Elster and Geitel, would seem to shew that the earth and not the atmosphere is the source of the penetrating radiation, but that certain waters and soils and salt deposits are comparatively free from radioactive substances, and can therefore act as efficient screens. It also seems evident from these experiments that the penetrating radiation, in some localities at least, does not come from a very great depth in the earth's crust.

The experiments made at Sestola, however, seem to point to the atmosphere as the source of the radiation.

In the following table the times of the day of the maxima and minima ionisation periods observed by the different investigators cited are collected. From this table it will be seen that very little connection exists between the times of the maxima and minima obtained in the different localities mentioned. It seems evident, too, after surveying all the recorded observations that the variations noted must be ascribed to changes in atmospheric conditions rather than to solar influences. No such regularity occurs in the variations as one should expect if the penetrating radiation had its origin in the sun.

TABLE I

Observer	Place	Maxima	Minima
Borgmann.........	St. Petersburg	3 p.m.	
Mach & Rimmer....	Vienna		Noon
Wood & Campbell..	Cambridge	7 to 11 a.m.	3 to 6 a.m
		9 to 11 p.m.	12n to 4 p.m.
McKeon...........	Washington	11 a.m.	5 to 7 a m.
		10.30 to 12 p.m	5 to 6.30 p m.
Strong............	Johns Hopkins	9 a.m.	7 a.m.
	University	10 p.m.	6 p.m.
Pacini............	Sestola	2 to 3 a.m.	7 to 8 a.m.
		9 to 10 a.m.	12n to 1 p.m.
Wulf..............	Valkenburg	8 to 9 a.m.	12 n.
	Holland	8 to 9 p.m.	12 m.

[1] Phys. Zeit. No. 1, 1905, p. 733.

In the course of his experiments at Toronto, C. S. Wright on several occasions made observations on the conductivity of air enclosed in metallic receivers over periods of time extending in some cases up to six or seven hours. Two typical sets of such observations are given in the following table :—

TABLE II

Time	q_0 = number of ions per c.c. per sec reduced to 0°C.
Dec. 24th	
10.23 a.m.	22.48
10.43 "	22.51
11.10 "	22.54
11.32 "	22.45
11.55 "	21.74
12.15 p.m.	22.73
12.40 "	21.96
1.00 "	22.94
Dec. 26th	
9.35 a.m.	22.44
9.58 "	21.86
10.20 "	21.87
10.45 "	22.25
11.05 "	22.96
11.28 "	22.79
11.50 "	22.53
3.55 p.m.	22.65
4.15 "	22.54
4.40 "	22.94
	Mean 22.45

and from the readings recorded in this table it will be seen that there is no evidence of any appreciable regular variation in conductivity, and it is to be noted also that the extreme values obtained for the conductivity did not differ from the mean by more than 3% of the latter.

It would seem from these observations, therefore, that very little diurnal variation exists in the penetrating radiation at Toronto. Wright's observations, however, were extremely limited in number and it was decided to extend them, to ascertain whether it would be necessary to modify in any way the conclusions which might be drawn from them. The following paper contains an account of these observations and it will be seen from the results that they point quite definitely to the absence of any regular diurnal variations.

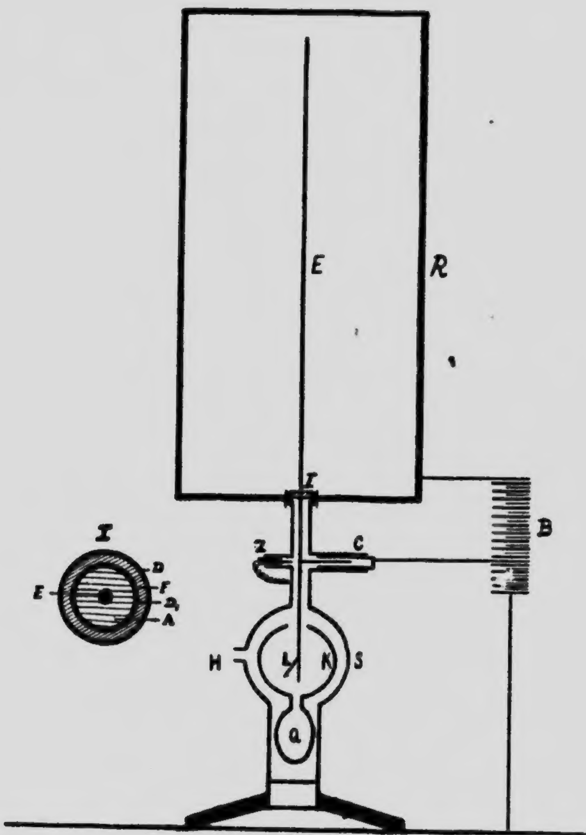

Fig I

II.—APPARATUS.

The measuring instrument used was the latest type of Wilson gold-leaf electroscope, and the arrangement of apparatus adopted is shewn in Fig. 1. The case of the electroscope was joined to earth and the leaf system to an electrode which passed up into the ionising chamber R. This chamber was insulated from the electroscope case, and could be charged as desired by means of the battery B to any

selected potential. Attached also to the leaf system was the inner tube of the sliding condenser C, for details of which the reader is referred to the paper by C. S. Wright mentioned above. In the measurements to be described the receiver was charged negatively to about 180 volts, which was found sufficient to insure a saturation current. The small quartz Leyden jar was kept at a negative potential of approximately 50 volts, and the slide tube condenser C to varying negative voltages depending on the sensibility desired.

By moving this condenser any charge acquired by the gold-leaf system through the conductivity of the air enclosed in R could be annulled. In the experiments the condenser was always moved over a standard distance and the time was taken for the conduction current to annul the deflection of the gold-leaf produced by the displacement of the sliding condenser.

The charge annulled per unit voltage applied to the compensator tube was .00501 e.s.u., a number which was determined by using the auxiliary parallel plate condenser supplied with the instrument.

Assuming the charge carried by an ion to be 3.4×10^{-10} e.s.u., it follows when the volume of the receiver is known and also the time required for the conduction current to annul a given quantity of electricity, that the number of ions per cc. per second " q " in the receiver R can be readily found.

III.—EXPERIMENTS.

Series I.

In this series of experiments the receiver R was made of sheet zinc. The potentials used were obtained from a set of small dry cells which remained constant over the whole range of measurements.

The receiver R, whose capacity was 31180 cc., was kept at a constant potential of 184.5 volts throughout, the Leyden Jar Q at 51.5 volts and the sliding condenser C at 13.2 volts. In this series of measurements the receiver was not hermetically sealed, so that barometric changes were necessarily followed by changes in the air content of the receiver.

The readings were taken visually and were commenced by a few preliminary observations over periods of from 4 to 6 hours' duration selected from different parts of the day. These were afterwards followed by observations taken continuously over a twenty-four hour period.

In the measurements for the shorter periods the apparatus was set up in a room in the Physical Laboratory and rested on a solid stone table which constituted the sill of one of the windows in the room.

The first observations were taken during the evening of Nov. 25, 1908, and are recorded in Table III. During the readings the barometer was practically stationary and stood at 753 mm. The curve in Fig. III illustrates the readings taken. The mean value of the readings it will be seen was 15.95 ions. In no case was there a deviation from the mean value of greater than 3%, and the curve shows no evidence of any marked variations which might be ascribed to changes in the radiations which contributed to the conductivity of the enclosed air.

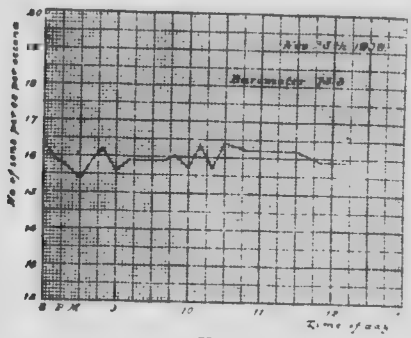

Fig. 2.

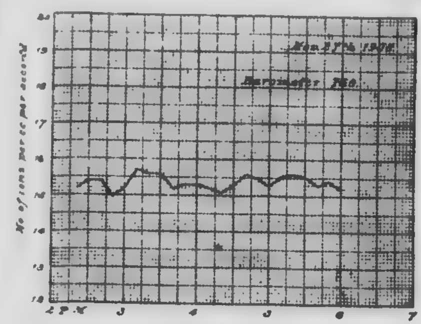

Fig. 3.

Similar sets of observations were taken on the afternoon and evening of Nov. 27, 1908. These are recorded in Tables IV and V, and illustrated by the curves shewn in Figs. III and IV. Here again it will be seen that the extreme deviation from the mean value did not exceed 3.5%. Moreover, the variations which did occur represent practically the limits of accuracy with which the readings could be taken by the measuring instrument.

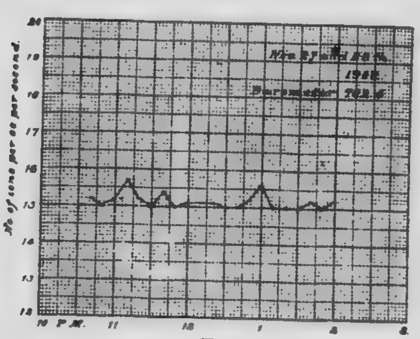

Fig. 4.

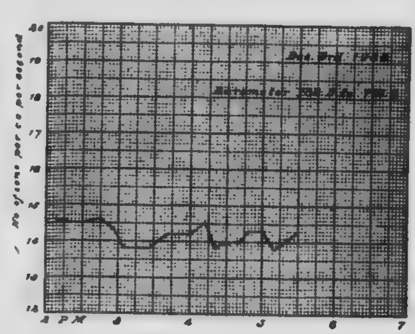

Fig 5.

Again, sets of observations were taken on the afternoons of December 3, 4 and 7. The results are recorded in Table VI, VII and VIII, and the corresponding curves are given in Figs. V, VI, and VII. From these it will be seen that in one case the deviations from the

mean were not greater than 1.5%, while in the other two they did not exceed 3%.

Further, the curves shown in Figs. II, III, IV, V, VI and VII indicated, it will be seen, but little variation during the periods of taking the readings. The readings from day to day, however, shewed considerable variation but these were no doubt due to variations in the amount of radioactive emanation present in the atmosphere. As the

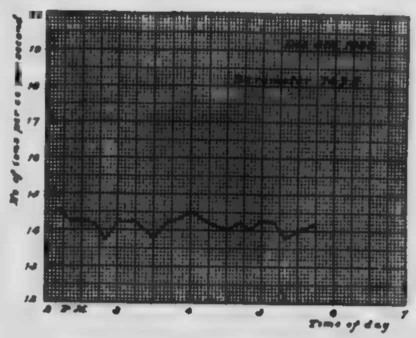

FIG. 6.

receiver was not hermetically sealed, the free interchange of air which this condition permitted could easily account for the differences noted.

A point of interest in connection with these observations and one which has been observed by other investigators was that the ionisation was greater when the barometric pressure was low than when it was high. A falling barometer would promote the effusion of gases

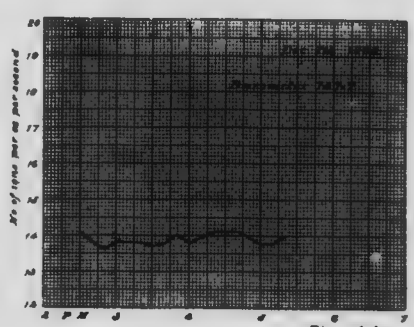

FIG. 7.

occluded in the soil, and this process of effusion would consequently result in an increase in the amount of emanation present in the air and so account for the higher conductivity.

It was also noted in these experiments that the conductivity of the air in the cylinder was less for corresponding barometric pressures when the ground was frozen and covered with snow than when the temperature was above freezing point and the ground bare. This is shewn in Table IX which contains the mean readings for observations taken under similar barometric conditions both with and without snow on the ground.

TABLE III

Time Nov. 25th, 1908	Temp.	No. of ions per c.c. per sec.
8.00 p.m.	20 °C	16.4
8.10 "	......	15.9
8.20 "	......	15.7
8.30 "	......	15.4
8.40 "	20.5°C	15.9
8.50 "	......	16.2
9.00 "	......	15.6
9.10 "	......	15.9
9.40 "	......	15.9
9.50 "	......	16.0
10.00 "	......	15.7
10.10 "	......	16.3
10.20 "	......	15.7
10.30 "	20.2°C	16.4
10.50 "	......	16.2
11.30 "	......	16.2
11.50 "	......	15.9
12.10 "	......	15.9

Mean 15.95. Extreme Deviation 3%.

TABLE IV

Time Nov. 27th, 1908	Temp.	No of ions per c.c. per sec.
2.20 p.m.	20°C	15.2
2.30 "	......	15.4
2.40 "	......	15.4
2.50 "	......	15.0
3.00 "	......	15.2
3.10 "	......	15.7
3.20 "	......	15.6
3.30 "	......	15.6
3.40 "	......	15.2
3.50 "	......	15.3
4.00 "	......	15.3
4.10 "	......	15.2
4.20 "	......	15.1
4.30 "	......	15.3
4.40 "	......	15.6
4.50 "	......	15.5
5.00 "	......	15.3
5.10 "	......	15.5
5.20 "	......	15.6
5.30 "	......	15.5
5.40 "	......	15.3
5.50 "	......	15.4
6.00 "	......	15.2

Mean 15.37. Extreme Deviation 2.6%.

TABLE V

Time Nov. 27 & 28, 1908	Temp.	No of ions per c.c. per sec.
10.40 p.m.	16.2°C.	15.2
10.50 "	"	15.0
11.00 "	"	15.2
11.10 "	"	15.7
11.20 "	"	15.2
11.30 "	"	15.0
11.40 "	"	15.4
11.50 "	"	15.0
12.00 a.m.	"	15.1
12.20 "	"	15.1
12.30 "	"	15.0
12.40 "	"	15.0
12.50 "	"	15.2
1.00 "	"	15.6
1.10 "	"	15.0
1.20 "	"	15.0
1.30 "	"	15.0
1.40 "	"	15.2
1.50 "	"	15.0
2.00 "	"	15.2

Mean 15.15. Extreme Deviation 3.5%.

TABLE VI

Time Dec. 3rd, 1908	Temp.	No. of ions per c.c. per sec.
2.00 p.m.	14°C.	14.5
2.10 "	......	14.6
2.20 "	......	14.5
2.30 "	......	14.5
2.45 "	......	14.6
2.55 "	......	14.3
3.05 "	......	13.8
3.15 "	......	13.8
3.25 "	......	13.8
3.40 "	......	14.2
3.50 "	......	14.2
4.00 "	...	14.2
4.10 "	......	14.5
4.20 "	......	13.8
4.30 "	......	14.0
4.40 "	......	14.0
4.50 "	......	14.3
5.00 "	......	14.3
5.10 "	......	13.8
5.20 "	......	14.0
5.30 "	......	14.3

Mean 14.2. Extreme Deviation 3%.

TABLE VII

Time Dec. 4th, 1908	Temp.	No. of ions per c.c. per sec.
2.10 p.m.	18. °C.	14.6
2.20 "	......	14.3
2.30 "	......	14.3
2.40 "	......	14.2
2.50 "	......	13.8
3.00 "	......	14.2
3.15 "	......	14.2
3.30 "	......	13.8
3..40 "	......	14.2
3.50 "	......	14.3
4.00 "	......	14.5
4.15 "	......	14.2
4.30 "	......	14.0
4.40 "	......	14.2
4.50 "	......	14.0
5.00 "	......	14.3
5.10 "	......	14.2
5.20 "	......	13.8
5.30 "	......	14.0
5.45 "	......	14.2

Mean 14.15. Extreme Deviation 3%.

TABLE VIII

Time Dec. 7th, 1908	Temp.	No. of ions per c.c per sec.
2.30 p.m.	......	14.1
2.40 "	......	13.6
2.50 "	......	13.6
3.00 "	......	13.8
3.10 "	......	13.8
3.20 "	......	13.8
3.30 "	......	13.6
3.40 "	......	13.8
3.50 "	......	14.0
4.00 "	......	13.8
4.20 "	......	14.1
4.30 "	......	14.1
4.40 "	......	14.1
5.00 "	......	13.8
5.10 "	......	13.8
5.20 "	......	14.0

Mean 13.87. Extreme Deviation 1.8%.

TABLE IX

No snow		Snow	
Barometer	Q	Barometer	Q
74.1	17.47	74.72	14.15
75.3	15.95	74.77	13.87
76.0	15.37	74.85	13.39
76.24	15.15	......	......

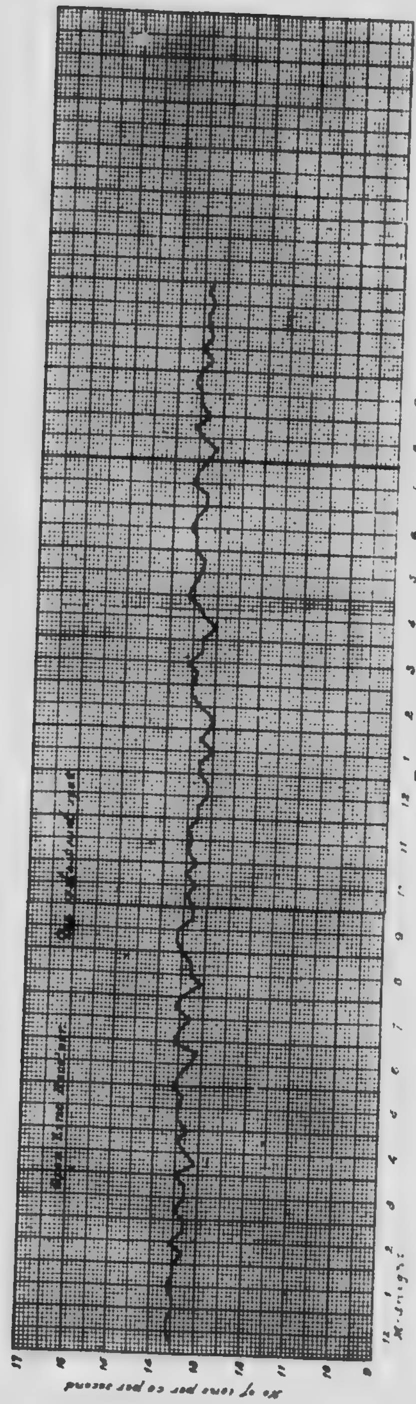
Time of day
No of ions per cc per second

FIG. 8.

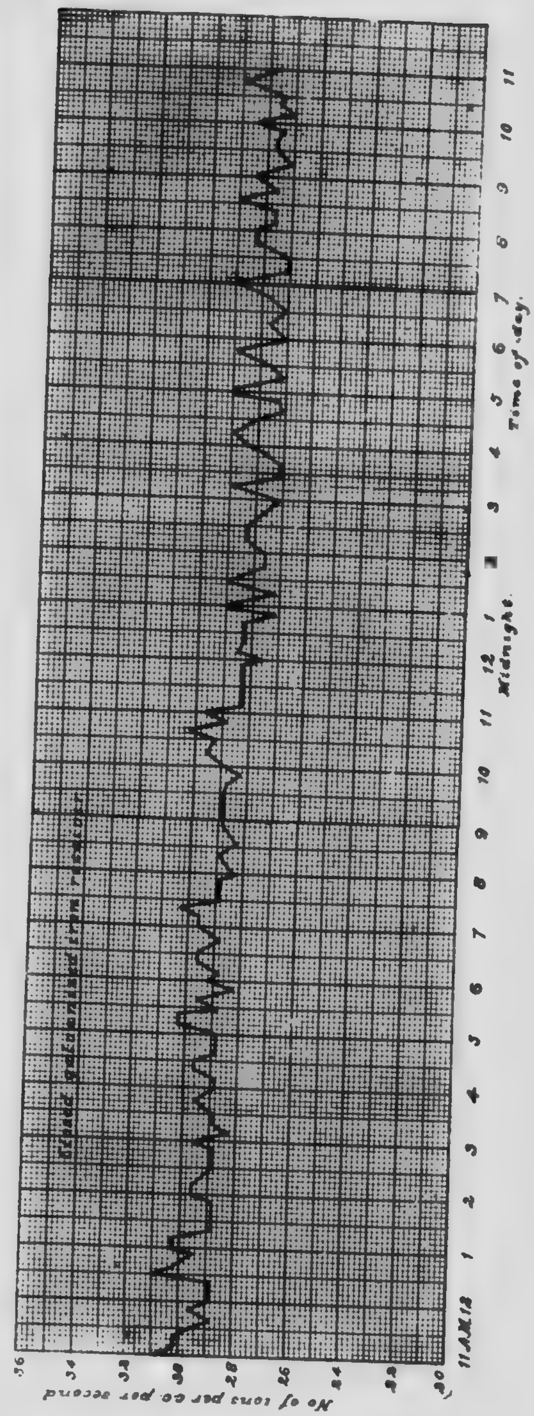
Time of day
Midnight
No of ions per cc per second

FIG. 9.

After completing the preliminary series of measurements just described it was decided to undertake a series extending over a twenty-four hour period. The readings were taken on December 18 and 19, 1908, in the Library of the Physical Laboratory. This was a large well-ventilated room facing the south east, and in it the apparatus was set up on a table close to one of the windows. During this set of observations the barometer remained fairly steady, the maximum change being from 746.3 to 749.5. The readings for this set of observations are given in Table X and a curve to illustrate them in Fig. VIII.

From an inspection of these readings and the curve, it will be seen that there is no evidence of a regular diurnal variation in the ionisation. The extreme deviations in the readings from the mean taken throughout the whole period were not greater than 3%, and as the instrument could not be used under the conditions of the experiment to give a greater accuracy than 2 or 3%, one is forced to conclude from these observations that at Toronto there are no daily variations in the intensity of the penetrating radiation greater in magnitude than such variations as came within the limits of sensibility of the measuring apparatus.

In the experiments which have been described no special precautions were taken to have the cylinder hermetically sealed. At a number of joints minute openings were left unclosed and so there must necessarily have been a constant interchange between the air inside the cylinder and that outside. It is worthy of note to observe that even with this interchange only very small variations in the conductivity of the air occurred.

TABLE X

Time Dec. 13th and 14th 1908	Temp.	Bar.	Ions per c.c.	Time	Temp.	Bar.	Ions per c.c.
p.m. 11.45	11.5	74.63	13.5	a.m. 11.30	....	.....	13.3
12.00	....	.....	13.6	11.45	....	.....	13.3
12.15	....	.....	13.5	12.00	....	.....	13.1
12.30	....	.....	13.5	12.15	....	.....	13.1
12.45	....	.....	13.5	12.30	....	.....	13.3

TABLE X—Continued

Time Dec. 13th and 14th 1908	Temp.	Bar.	Ions per c.c.	Time.	Temp.	Bar.	Ions per c.c.
a.m. 1.00	....	.....	13.6	a.m. 12.45	....	.....	13.3
1.15	....	.....	13.5	1.00 p.m.	....	.....	13.0
1.30	....	.....	13.5	1.15	....	.....	13.3
1.45	....	.....	13.3	1.30	....	.....	13.1
2.00	....	.....	13.6	1.45	....	.....	13.0
2.15	....	74.74	13.3	2.00	20.0	74.95	13.3
2.30	...	...	13.3	2.15	....	...	13.5
2.45	....	....	13.5	2.30	....	.....	13.5
3.00	....	...	13.3	2.45	....	.....	13.4
3.15	.	.....	13.3	3.00	....	.....	13.6
3.30	..	....	13.5	3.15	....	.....	13.3
3.45	11.0	...	13.1	3.30	...	.....	13.3
4.00	...	...	13.3	3.45	....	.....	13.0
4.15		..	13.5	4.00	..	.....	13.3
4.30	...	.	13.3	4.15	..	.....	13.4
4.45	.	74.85	13.5	4.30	....	.....	13.6
5.00	..	...	13.5	4.45	....	.....	13.5
5.15	...	....	13.4	5.00	....	74.86	13.4
5.30	...	.....	13.6	5.15	....	.....	13.3
5.45	..	....	13.5	5.30	....	.....	13.5
6.00	...	....	13.3	5.45	....	.....	13.5
6.15	...	.....	13.1	6.00	....	.....	13.6
6.30	....	.....	13.6	6.15	...	.....	13.5
6.45	....	.....	13.5	6.30	....	.....	13.3
7.00	....	.....	13.3	6.45	....	.....	13.3
7.15	....	.....	13.6	7.00	....	.....	13.6

TABLE X—Continued.

Time Dec. 13th and 14th 1908	Temp.	Bar.	Ions per c.c.	Time.	Temp.	Bar.	Ions per c.c.
a.m. 7.30	....	74.96	13.5	p.m. 7.15	....	.....	13.5
7.45	....	.....	13.1	7.30	....	.....	13.3
8.00	....	.....	13.3	7.45	....	.....	13.1
8.15	....	.....	13.3	8.00	....	74.95	13.4
8.30	....	.....	13.5	8.15	....	.....	13.6
8.45	16.0	.....	13.6	8.30	....	.....	13.3
9.00	....	.....	13.6	8.45	....	.....	13.5
9.15	....	.....	13.3	9.00	....	.....	13.5
9.30	....	.....	13.3	9.15	....	.....	13.6
9.45	....	.....	13.5	9.30	....	.....	13.5
10.00	19.0	.....	13.3	9.45	....	.....	13.3
10.15	....	.....	13.5	10.00	....	.....	13.5
10.30	....	.....	13.3	10.15	....	.....	13.3
10.45	....	.....	13.5	10.30	....	.....	13.4
11.00	....	.....	13.4	10.45	....	.....	13.4
11.15	21.0	.....	13.5	11.00	16.5	.....	13.3
.....	....	.....	....	11.15	....	.....	13.4
.....	....	.....	....	11.30	....	.....	13.3

IV.—EXPERIMENTS.

SERIES II.

In order to submit the question of a diurnal change in the intensity of the penetrating radiation to a further test a second set of readings was taken over a period of twenty-four hours. In these a cylinder of galvanized iron was used of capacity 29950 ccs. The electrode in this case was divided into sections, the one portion extending from the gold-leaf to the top of the electroscope and the other

being supported by insulating materials in position in the cylinder. The insulated electrode in the receiver was protected by an earthed guard tube which was also sealed in position and finally all the joints of the cylinder were made air-tight by means of either solder or marine glue.

When the cylinder was placed in position above the electroscope a small spring made metallic contact between the two sections of the electrode.

TABLE XI

Time Dec. 18th and 19th, 1908	Temp.	Bar.	Ions per sec.	Time	Temp.	Bar.	Ions per sec.
a.m. 11.00	18°C	74.4	30.9	a.m. 10.15	....	.....	29.6
11.10	....	.....	30.2	10.30	....	.....	29.3
11.20	....	.....	30.2	10.40	....	.....	30.3
11.30	....	.....	29.6	10.50	14.5°C	.....	28.9
11.40	....	.....	28.9	11.00	....	.....	29.6
11.50	....	.....	29.6	11.10	....	.....	28.3
12.00	....	.....	28.9	11.20	....	.....	28.3
12.10	....	.....	28.9	11.30	....	.....	28.3
12.20	....	.....	28.9	11.40	....	.....	28.3
12.30	....	.....	30.9	11.50	....	.....	28.3
12.40	....	.....	30.2	12.00	....	.....	27.6
12.50	24°C	.....	29.5	12.10	....	.....	28.5
1.00 p.m.	....	.....	30.3	12.20	....	.....	28.3
1.10	....	.....	30.3	12.30	....	.....	28.3
1.20	....	.....	28.9	12.40	....	.....	28.3
1.30	....	.....	28.9	12.50	....	.....	27.1
1.40	....	.....	28.9	1.00 p.m.	....	.....	28.9
1.50	....	.....	28.9	1.15	....	.....	27.1
2.00	....	.....	29.6	1.30	....	.....	28.9
2.10	....	.....	29.6	1.45	....	.....	27.6
2.20	....	....	29.2	2.00	....	.....	27.6

TABLE XI—Continued

Time Dec. 18th and 19th, 1908	Temp.	Bar.	Ions per sec.	Time.	Temp.	Bar.	Ions per sec.
p.m. 2.30	....	.....	28.9	p.m. 2.15	....	.....	28.3
2.40	....	.....	28.9	2.30	....	.....	28.3
2.50	20°C	74.7	28.9	2.45	....	.....	27.6
3.00	....	.....	29.6	3.00	....	.....	27.1
3.10	....	.....	28.3	3.15	....	.....	28.9
3.20	....	.....	28.9	3.25	....	.....	27.1
3.30	....	.....	28.9	3.40	....	.....	27.1
3.45	....	.....	29.6	3.50	....	.....	27.6
4.00	....	.....	28.9	4.00	....	.....	28.3
4.10	....	.....	28.9	4.15	....	.....	28.9
4.20	....	.....	29.6	4.25	....	.....	28.3
4.30	....	74.95	29.6	4.40	....	.....	27.1
4.40	....	.....	28.9	4.50	....	.....	27.3
4.50	....	.....	28.9	5.00	....	.....	28.9
5.00	....	.....	28.9	3.15	....	.....	27.1
5.10	....	.....	30.3	5.30	....	.....	27.6
5.20	....	.....	30.3	5.45	....	.....	28.9
5.30	....	.....	28.9	6.00	....	.....	27.1
5.40	....	.....	29.6	6.15	....	.....	27.6
5.50	....	.....	28.3	6.30	....	.....	27.1
6.00	....	.....	29.2	4.45	....	.....	27.6
6.10	....	.....	28.9	7.00	....	.....	28.9
6.20	....	.....	29.6	7.15	....	.....	27.1
6.30	....	.....	29.6	7.30	....	.....	27.1
6.45	....	.....	28.9	7.45	....	.....	28.3
7.00	....	.....	29.6	8.00	....	.....	28.3

TABLE XI—Continued

Time Dec. 18th and 19th, 1908	Temp.	Bar.	Ions per sec.	Time	Temp.	Bar.	Ions per sec.
p.m. 7.10	....	75.2	29.6	p.m. 8.10	....	.....	27.6
7.20	....	.....	30.3	8.20	....	.....	27.6
5.30	....	.....	28.9	8.35	....	.....	28.9
7.40	....	.....	28.9	8.45	....	.....	27.6
7.50	....	.....	28.9	9.00	....	.....	28.3
8.00	....	.....	28.3	9.15	....	.....	27.1
8.10	....	.....	28.7	9.30	....	.....	27.6
8.20	....	.....	28.9	9.40	....	.....	27.6
8.35	....	.....	28.3	9.50	....	.....	27.4
8.50	....	.....	28.9	10.00	....	.....	28.3
9.00	....	.....	28.9	10.10	....	.....	27.1
9.10	....	.....	28.9	10.20	....	.....	27.6
9.20	....	.....	28.9	10.30	....	.....	27.4
9.30	15°C	.....	28.9	10.45	....	.....	28.9
9.40	....	.....	28.8	11.00	....	.....	28.6
9.50	....	.....	28.3	.....	....	.....	....
10.00	....	.....	28.9	.....	....	.....	....

A small glass u-tube mercury manometer was also sealed into the side of the receiver to give indication of any air leak in the vessel.

In preparing for the observations, care was taken to thoroughly clean the inside of the receiver and freshly filtered air was introduced into it to a pressure slightly greater than atmospheric pressure. This slight excess of the inside pressure over that of the atmosphere outside produced a difference of level in the two arms of the manometer. From the manner in which this difference of level followed the changes in the barometer it was soon seen that the receiver was air-tight, and therefore in the condition desired for the observations.

When this point was made certain the readings were commenced. These were taken on Dec. 18 and 19, 1908. They are given in Table XI and a curve drawn from them is shown in Fig. IX.

This curve also, it will be seen, shews no regular periodic variation. Further, the greatest deviation from the mean value was not more than 4%. The capacity of the measuring system was greater in this set of measurements than in the previous one but the same voltage was applied to the sliding condenser as in the previous measurements. The result of this change was to reduce the sensibility of the apparatus slightly, and this would account for the 4% variations in the readings apart altogether from any variation in the conductivity.

A point of special interest in connection with the readings is the gradual drop which they indicate in the conductivity of the enclosed air. This drop, which has been observed by others in similar measurements, was no doubt due to the gradual removal by the field of the suspension particles designated by Langevin[1] as "large ions" and first investigated by him. When the air was introduced into the receiver it was passed through a tube filled with cotton wool. This filter it was thought would remove all the dust and fine particles in suspension, but it was found after the completion of the measurements that when air filtered in the same way was led into an expansion cloud chamber of the C. T. R. Wilson type it still contained suspension particles in abundance which acted as cloud nuclei. During these measurements the barometer only changed from 744 to 752 mm.

On account of the higher radioactivity in the walls of this receiver the conductivity of the air in this case was about double its value in the early measurements. This enabled the writer to take a greater number of observations in a given time, but on account of the failure to increase the voltage of the condenser tube it did not contribute anything to the sensitiveness with which the readings were taken.

V.—EXPERIMENTS.

Series III.

The experiments which have been described up to the present were all conducted indoors, and as the walls of the Physics Building very probably reduced in some degree the intensity of the penetrating radiation, it was thought best to complete the series of observations by placing the receiver of the apparatus outside and so exposed directly to the atmosphere.

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[1] Comptes Rendus, 140, pp. 232, 1905.

To accomplish this the electroscope was taken to the attic of the building and set up beneath a small opening in the roof. The receiver was placed over this opening on insulating supports on the roof and the electrode which it carried was joined to that of the leaf system by the insertion of a light metal rod 1 2-3 metres in length. A guard tube was also added to protect this added length to the electrode.

In setting up the apparatus this time a lining of thick sheet zinc was inserted in the receiver which had been carefully abraded with fine glass paper and then thoroughly washed in turn with dilute hydrochloric acid, ammonia, methyl alcohol, and distilled water. Fresh filtered air was drawn into the receiver and it was then hermetically sealed. Readings were taken immediately afterwards. In this case also it was noticed that the conductivity of the air gradually decreased and ultimately assumed a steady value. In the initial measurements the conductivity corresponded to as high as 19 ions per cc. per second, but in the steady state it approximated to the generation of only 11.0 ions per cc. per second.

This low value illustrates the great differences which exist in the radioactivity of different metals. With the galvanised iron cylinder alone it will be remembered that the conductivity corresponded to the production of about 35 ions per cc. per second. The insertion of the zinc lining it will be seen therefore cut off by far the greater portion of the radiation from the galvanised iron. The reduction in the conductivity of the enclosed air necessarily made that portion contributed by the penetrating radiation of greater relative importance and it was thought that a more severe test would thus be available for the detection of diurnal variation. It was found, however, that the insertion of the long electrode greatly reduced the sensibility of the electroscope. By the addition of this the capacity of the instrument was nearly trebled, and consequently although the displacement of the gold leaf for a given movement of the condenser tube could be increased by adding to the voltage of the latter still this device had the defect of adding to the time of taking a reading, and as it was desirable to have the readings taken as frequently as possible it was found necessary therefore to apply only a moderate voltage to the condenser. For this purpose a potential of 21 volts was maintained on the condenser tube, and this permitted readings to be taken, though with diminished accuracy, every 15 or 20 minutes.

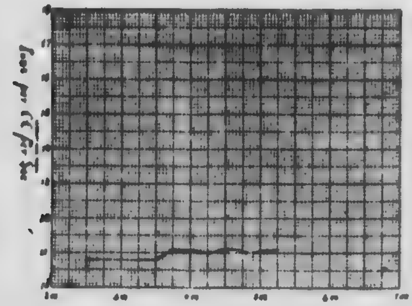

FIG. 10.

TABLE XII

Time March 15th, 1909	Ions per c.c. per sec.
2.30 p.m.	10.8
2.45 "	10.8
3.00 "	10.8
3.15 "	10.8
3.30 "	10.8
3.45 "	11.1
4.00 "	11.1
4.15 "	11.0
4.35 "	11.1
4.55 "	11.0
5.15 "	11.1

Barometer, 75.73. Bright day ; snow melting.

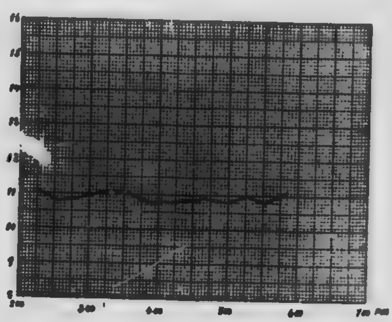

FIG. 11.

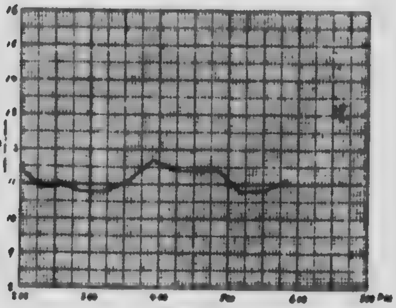

FIG. 12.

TABLE XIII

Time March 22nd, 1909	Ions per c.c. per sec.
2.15 p.m.	11.1
2.35 "	10.8
2.55 "	10.9
3.15 "	11.1
3.35 "	11.1
3.55 "	10.8
4.15 "	10.8
4.40 "	10.9
5.00 "	10.8
5.15 "	11.0
5.35 "	10.8
5.50 "	11.1

Temp, 12° to 7° C. Barometer 76.04 cms.
Bright day; snow going away rapidly.

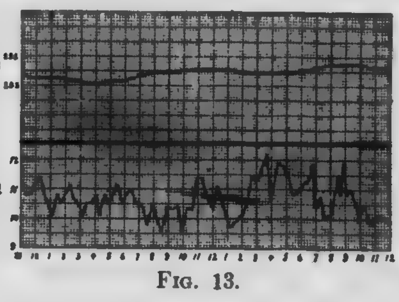

FIG. 13.

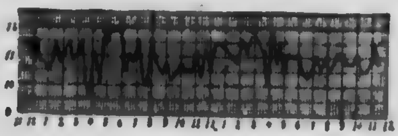

Fig. 14.

TABLE XIV

Time March 26th, 1909	Ions per c.c. per sec.
2.00 p.m.	11.4
2.20 "	10.9
2.35 "	11.0
2.55 "	10.8
3.10 "	10.8
3.35 "	11.1
3.55 "	11.7
4.15 "	11.4
4.35 "	11.4
4.50 "	11.4
5.10 "	10.8
5.30 "	10.8
5.50 "	11.1

Ground frozen the previous night. Bright day.
Temp. 8°C. Barometer 74.22 cms.

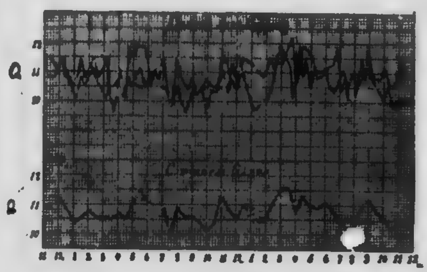

Fig. 15.

TABLE XV

Time March 28th and 29th, 1909	Ions per c.c.	Barometer	Time	Ions per c.c.	Barometer
11.20 p.m.	10.8	29.235 inches	11.30 a.m.	10.8	.... inches
11.40 "	10.8	....	11.45 "	13.2	....
12.00 a.m.	11.2	29.227 "	12.00 "	10.4	29.255
12.20 "	11.4	....	12.15 p.m.	11.1	....
12.35 "	10.8	....	12.45 "	10.35	....
12.50 "	10.5	29.227 "	1.05 "	9.7	29.256 "
1.10 "	10.1	....	1.35 "	9.9	....
1.25 "	10.8	....	1.55 "	10.1	....
1.40 "	10.5	....	2.20 "	10.5	29.246 "
2.00 "	10.8	29.220 "	2.40 "	11.4	....
2.15 "	11.1	....	3.00 "	11.3	29.241 "
2.35 "	10.7	....	3.40 "	12.2	....
2.50 "	10.5	29.212 "	4.00 "	10.6	29.239 "
3.10 "	10.1	....	4.20 "	11.9	....
3.25 "	10.5	....	4.40 "	11.8	....
3.40 "	10.5	....	5.05 "	11.5	29.243 "
4.00 "	10.8	29.204 "	5.25 "	10.8	....
4.15 "	10.1	....	5.45 "	10.9	29.249 "
4.35 "	10.8	....	6.10 "	11.2	....
4.50 "	10.5	29.213 "	6.30 "	11.3	....
5.10 "	10.8	....	6.45 "	11.9	....
5.25 "	11.1	....	7.00 "	10.4	29.264 "
5.55 "	10.5	....	7.15 "	10.8	....
6.10 "	10.8	29.216 "	7.30 "	10.1	....
6.30 "	10.8	....	7.45 "	10.1	....
6.45 "	10.5	....	8.00 "	10.1	29.276 "
7.00 "	10.5	29.233 "	8.20 "	11.5	....
7.15 "	10.4	....	8.35 "	10.8	....

TABLE XV—Continued.

Time April 4th and 5th, 1909	Ions per c.c.	Barometer	Time	Ions per c.c.	Barometer
7.35 p.m.	9.8	.... inches	8.50 p.m.	11.9	29.276 inches
7.55 "	10.5	....	9.05 "	10.8	....
8.13 "	9.9	29.243 "	9.20 "	11.1	....
8.35 "	9.6	....	9.40 "	10.5	....
8.55 "	10.4	29.245 "	9.55 "	10.1	29.273 "
9.15 "	10.3	....	10.15 "	10.5	....
9.35 "	10.45	....	10.30 "	9.9	....
9.55 "	9.6	29.257 "	10.50 "	9.9	29.266 "
10.15 "	10.35	....	11.05 "	10.1	....
10.35 "	10.3	....	11.20 "	10.1	....
11.00 "	11.4	29.255 "			

TABLE XVI

Time April 4th and 5th, 1909	Ions per c.c.	Barometer	Time	Ions per c.c.	Barometer
11.30 p.m.	11.5	29.641 inches	11.20 a.m.	10.3	.... inches
11.50 "	11.1	....	12.00 p.m.	10.6	29.471
12.10 a.m.	11.5	29.622 "	12.20 "	11.5	....
12.25 "	10.8	....	12.40 "	11.4	....
12.40 "	10.8	....	1.00 "	11.3	29.453 "
1.00 "	10.5	29.607 "	1.15 "	11.15	....
1.15 "	10.8	....	1.50 "	10.8	....
1.30 "	11.5	....	2.10 "	11.5	....
1.50 "	10.8	29.589 "	2.25 "	11.15	....
2.05 "	11.1	....	2.55 "	11.9	....
2.25 "	11.5	....	3.15 "	11.5	....
2.40 "	10.8	....	3.35 "	11.15	....

TABLE XVI—Continued.

Time March 28th and 29th, 1909	Ions per c.c.	Barometer	Time	Ions per c.c.	Barometer
3.00 a.m.	11.1	29.579 inches	3.50 p.m.	10.1	.... inches
3.15 "	11.5	....	4.10 "	11.9	....
3.30 "	10.1	....	4.25 "	10.8	....
3.50 "	9.6	29.557 "	4.40 "	11.5	....
4.05 "	11.1	....	5.00 "	10.5	....
4.25 "	10.1	....	5.15 "	11.15	....
4.45 "	11.9	....	5.35 "	11.00	....
5.00 "	11.5	29.554 "	5.55 "	11.15	....
5.15 "	11.9	....	6.15 "	10.5	....
5.30 "	11.9	....	6.35 "	10.3	....
5.45 "	11.9	....	6.55 "	10.6	....
6.00 "	11.5	29.533 "	7.15 "	11.15	....
6.15 "	10.5	....	7.30 "	10.55	....
6.30 "	11.1	....	7.50 "	11.00	....
6.45 "	10.8	29.517 "	8.05 "	10.5	....
7.05 "	11.5	....	8.24 "	10.8	....
7.25 "	10.1	....	8.40 "	11.15	....
7.40 "	10.0	....	8.55 "	11.15	....
8.00 "	11.5	29.516 "	9.10 "	10.8	....
8.15 "	10.8	....	9.30 "	10.8	....
8.45 "	10.4	....	9.45 "	10.8	....
9.00 "	10.8	29.507 "	10.00 "	11.15	....
9.15 "	10.2	....	10.20 "	10.5	......
9.40 "	10.4	....	10.35 "	10.5	....
10.00 "	10.7	29.497 "	10.53 "	10.8	....
10.20 "	10.5	....	11.10 "	11.5	....
10.45 "	10.5	29.493 "	11.30 "	10.8	....
11.00 "	11.15	....			

With the apparatus set up in the manner just described sets of readings were taken during the afternoons of March 15, 22 and 26, 1909. The results of these measurements are recorded in Tables XII, XIII and XIV, and curves illustrating them are shewn in Figs. X, XI and XII.

The readings for the three afternoons, it will be seen, approximated to 11 ions per cc. per second.

By comparing the three curves it will be seen that although the readings were not uniformly regular still no periodic daily variation was brought into evidence. On March 28 and 29 and again on April 4 and 5, 1909, readings were again taken with this apparatus continuously over periods of twenty-four hours. The readings taken during these observation periods are given in Tables XV and XVI and the corresponding curves are shewn in Figs. XIII and XIV. These readings it will be seen are far from being so uniform as those of the earlier observations. The variations from the mean it will be seen are very considerable, and are attributable in the judgment of the writer, to the lack of sensitiveness in the instrument and the consequent difficulty in taking the readings, rather than to any variations in external influences.

In Fig. XIII the barometric curve is drawn for the corresponding twenty-four hour period. From an inspection of the two curves there does not appear to be any connection between the changes in conductivity and the changes in atmospheric pressure as indicated by the barometric readings.

In order to see whether a combination of the curves shewn in Figs. XIII and XIV would give any indication of a pronounced maximum and minimum conductivity the two curves were compounded by taking the mean of the readings for the same time of the day. The individual curves are shewn overlapping in the upper portion of Fig. XV, and the compound curve is shewn at the bottom of the same figure. From the figure, however, it is impossible to draw the conclusion that any maximum or minimum conductivity was associated with any particular hours of the day.

While the lack of sensibility in the measuring instruments prevented these later observations from leading to as satisfactory conclusions as might be desirable, still they agree with the earlier ones in failing to point to any variation of a regular diurnal character, and in this they seem to show that the conditions at Toronto are somewhat different from those which prevail in a number of other localities where similar observations have been made.

The writer had hoped to continue the investigation out in the open country with the electroscope arranged as adjusted for maximum

sensibility, and possibly, too, with auxiliary apparatus attached for taking the readings automatically in place of taking them visually, but time has not permitted and the further investigation of this point has been of necessity deferred.

VI.—SUMMARY.

In summarising the results of the investigation the following are the chief points which have been noted :

a With an open receiver.

1. No daily regular maxima or minima conductivities were observed.

2. Changes in conductivity occurred from day to day which seemed to be directly connected with concurrent barometric changes.

3. The conductivity was found to be slightly less when the ground was frozen and covered with snow, than when it was bare and the temperature was above freezing point.

b With a closed receiver.

1. Larger variations in the conductivity were observed but no regular diurnal maxima or minima values were noted. The larger variations in the conductivity were attributed to a lack in the sensitiveness of the measuring electroscope.

2. Different metals which were used in the construction of the receiver were found to possess different activities, zinc being very low.

3. Atmospheric air, even when well filtered through cotton wool, was found to contain many suspension particles.

As a general result of the investigation it would appear that the soil contributes by far the greater proportion of the penetrating radiation present at the earth's surface at Toronto, and by comparison any that may have its source in the atmosphere or in the sun may be considered to be negligible in amount.

In closing I wish to express my gratitude to Professor McLennan for his kindness throughout the research, for suggestions and for assistance in overcoming mechanical difficulties.

My best thanks are also due Mr. E. F. Burton for his kindness in taking a number of readings.

UNIVERSITY OF TORONTO STUDIES

PAPERS FROM THE PHYSICAL LABORATORIES.

The "Papers from the Physical Laboratories," issued as a special series of University of Toronto Studies, date from the year 1900. Nos. 1-17 were published by the Physical Department in a very limited edition and are no longer in print. For the sake of a complete record the numbering of the Papers, as forming a series of University of Toronto Studies, is made continous with the earlier series and commences with No. 18. The earlier numbers, except those given below, are not now available either for sale or gift.